From Energy Efficiency to Integrated Sustainable Urbanism in Residential Development in China

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Abstract

China has adopted Sustainable Development as a national strategy for all industries. In the civil construction sector, sustainability is regarded as the development of Green Building and since 2000, China has introduced a series of policies and laws to promote Green Building.

Green Building is defined as the buildings that are ‘energy-efficient, land-efficient, water-efficient and material-efficient’, emit ‘minimal pollution’ during their entire life cycle, and meet specifications on indoor environment. However, energy efficiency is the central issue in current Green Building development in China, while issues of resources and pollution are neglected, partly due to China’s energy structure.

This thesis examines pathways towards creating more comprehensive frameworks on how residential areas in China could be constructed more sustainably in hot-summer/cold-winter areas. The main method used to examine the specifications of Green Residential Building in China was through case studies. The thesis provides a general overview of the current green trend in China and, in an attempt to identify a suitable approach for China’s unique situation, presents a specific analysis of three specific cases representing different types of Green Building: Modern Vernacular Architecture, Eco-office and Mass-housing, according to their features in scale, location and function.

A specific integrated sustainability analysis was carried out on the Landsea Housing Project in Nanjing, a hot-summer/cold-winter zone. Hammarby Sjöstad, a cutting edge project in Stockholm, was used as a reference area from which experiences could be drawn for China. The aim was to improve the framework for sustainable construction of residential buildings in China, from energy efficiency to integrated sustainability.

The thesis also discusses the relationship between economic growth and energy consumption in the fast-growing situation, presents several scenarios depicting energy and comfort and makes suggestions for China. The roles of government, developers and residents are addressed. It is argued that an adaptive and holistic approach, which must be expanded on both the spatial and temporal scales, should be established for Green Residential Building development in China, as an effective way to meet the sustainability goal.

Keywords: China; Green Building; New Cave house; Eco-office; Mass-Housing; Green Residential Development, Industrial Ecology, Landsea Housing Project, Hammarby Sjöstad; Systems Thinking
Acknowledgements

This research was initiated by an academic collaboration between Industrial Ecology, Royal Institute of Technology (KTH), Sweden and the School of Architecture, Southeast University (SEU), China. The objective of this collaboration is to develop ideas on design and research of sustainable urbanism and architecture in China. In September 2007, as part of the collaboration, I came to KTH to begin the doctoral programme under the supervision of Prof. Ronald Wennersten, Head of Industrial Ecology. My study in KTH was sponsored by the Joint China Scholarship Council (CSC)-KTH Program.

Prof. Ronald Wennersten has worked in the field of Industrial Ecology, the science of sustainable development, for a long time, and his comprehensive interests include Environmental Impact Assessment, Sustainable Urban Development, Building Ecology, Risk Management, etc. His comprehensive academic experience gave my study a solid scientific background, which is generally a weak point of research performed by architects. His intelligence and keenness inspired me greatly to pursue my research. His wise understanding of the Chinese situation and involvement in research in China made my study here more meaningful and practical. I am so grateful for his important guidance and supervision.

During my research, I attended the course ‘Beyond Oil: Shanghai and Beyond Desire: Los Angeles’ at the Department of Architecture, Royal University of Fine Arts (KKH). Lectures at KKH, discussions with Prof. Henrietta Palmer and lecturer Michael Dudley, and studio work by my classmates also expanded my thoughts greatly on the topic of sustainable urbanism.

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Stockholm, April 2010
Zhichang Cai
Outline and list of appended papers

This thesis is based on three papers that describe the different studies carried out. Paper I presented an analysis of the current large-scale urbanisation in China from comprehensive perspectives and listed the main challenges concerning long-term sustainable urbanism in China. Paper II focused on the building industry, particularly the current development towards Green Building which is regarded as the goal of sustainability in the building industry. Three cases, different in building type, scale, location, investment and objectives, were analysed from social, economic and technical perspectives in Paper II to obtain a general image of how sustainable buildings are developed in China. Paper III continued the study initiated in Paper II, made a deep and detailed case study of the third case in that paper and examined how to develop more comprehensive frameworks, from energy efficiency to integrated sustainability, for residential areas in China.


I examined the main challenges concerning long-term sustainable urbanism in China and analysed the current situation in Chinese urbanisation. I also wrote the paper.


I carried out the case studies, made the analysis and wrote the paper. I also made an oral presentation of the paper at the conference.


I carried out the case study, made the analysis and wrote the paper.


I carried out the theoretical study, made the analysis and wrote the paper.
**List of abbreviations**

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<th>Description</th>
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<tr>
<td>IE</td>
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<td>Life Cycle Assessment</td>
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<td>M/EFA</td>
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1 Introduction

1.1 Aim and objectives

The overall aim of this thesis was to map pathways towards sustainable urbanism in China and specifically develop ideas on more comprehensive frameworks for how residential areas in China could be constructed in a more sustainable way in hot-summer/cold-winter areas. To achieve the aim, the specific objectives of the work were to:

1. Summarise the challenges and features of current large-scale urbanisation in China and present some preliminary proposals on possible future development.

2. Describe the background and specific problems concerning development of residential areas in China and the existing legislation and standards in China, describe the definition of Green Building in the Chinese context, and analyse the current Green Building development in China by case studies.

3. Describe fundamental differences in China and Europe concerning sustainable development in urban areas.

4. Use a detailed case in China as an example of modern development of residential areas and discuss the sustainability aspects of this area.

5. Describe experiences of the process and results from a cutting edge project in Europe, Hammarby Sjöstad, developed from a more comprehensive framework as a reference area where experiences can be drawn for China, compare the two cases and draw conclusions on how a more general framework for sustainability in new areas in China can be developed.

6. Discuss the relationship between economic growth and energy consumption in the fast-growth situation, present a number of scenarios depicting energy and comfort issues and make suggestions for China.

1.2 Background

1.2.1 General conditions

In 2008, more than 50% of the global population was living in cities, which had never happened before in human history, and this figure will probably rise to 69.9% by 2050 (UN DESA, 2008). This also means an Urban Era for the world and unavoidable urbanisation. Together with the growing total population on earth, this future trend makes the search for solutions to establish cities with the emphasis on long-term sustainability a high priority.

Most of the current studies on sustainable urbanism are based on situations in the developed world. However, there is an urgent demand for sustainable urbanism applications for developing countries, which are very different from the developed countries in terms of economic ability, population, land conditions, policy and so on. Furthermore, most future urbanisation will happen in developing countries.

For instance, the past 30 years (1978-2008) have witnessed rapid, large-scale urbanisation in
China, both as a force and as a result of the rapid economic growth which started in 1978 due to the Economic Reform. It is projected that from 2003 to 2020, 420 million people will have moved into cities in search of a better life (Wang, 2005). This mass migration and increasing urbanisation are accompanied by increasingly critical challenges such as energy scarcity, air pollution, land abuse, environmental degradation, urban population explosion, etc.

The fundamental fact is that China is a huge developing country, both in population (1.3 billion) and in territory size (9.6 million km², excluding oceanic territory). Although China is abundant in many types of resources in terms of total reserves, it is very poor in terms of per capita reserves because of its huge population. China is especially scarce in arable land and water. The arable land per capita of China was 934 m² in 2005, which is 40% of the world average level (Ministry of Land Resources, 2005). The water resource per capita was 2125 m³ in 2005 (World Resources Institute, 2008) and 1927 m³ in 2006 (National Bureau of Statistics of China, 2007), which is around a quarter of the world average (8210 m³ in 2005; World Resources Institute, 2008).

Furthermore, China’s energy supply relies too much on coal, which accounted for 69.4% of primary energy consumption in 2006 (Figure 1) (National Bureau of Statistics of China, 2007). This heavy reliance on coal has caused severe air pollution and acid rain in China, as well as producing the main GHG emissions.

![Primary Energy Supply Structure of China, 2006](image)

*Figure 1: Energy Structure of China, 2006.*
*Source: Statistical Yearbook of China, 2007*

From an economic point of view, although China has a huge total GDP (1,889,930 million dollars in 2005), it is still a developing country, with very low GDP per capita ($1,449 in 2005, while the world average was $5,647 in the same year (World Resources Institute, 2008). However, with the improvement in average quality of life along with the economic growth, more and more energy and resources are being demanded by China.

Another fact about China is its long history and great variation in different sub-cultures. Along with its diverse geographical and climate zones, China has high richness in vernacular
architecture. These traditional buildings are mainly located in rural areas and still house a large proportion of the rural population. They are also of great importance due to the traditional wisdom embedded in their designs and constructions and related to local contexts. The following are some examples.

**Courtyard House**, which represents the northern residential typology, arranges rooms around an internal courtyard to enhance natural ventilation and allow in more sunshine. Family life is organised around the yard (Figure 2).

**Elevated House**, which represents the south-western residential typology, puts main rooms on the second floor and leaves the ground floor open to cope with the high humidity and hot climate.

**Cave House**, which represents the north-western residential typology, was built from a cave in the earth and could have a cool indoor temperature in hot summer and a warm one in cold winter because of the thick earth as a good insulator.

**Water-town**, which represents the south-eastern typology of small towns, was built along rivers. The rivers function as the main communication networks and also cool the houses in hot summer.

**Tu Lou or Earth Tower**, which represents an exclusive Ke Jia (meaning migrant) ethnic residential typology, was built to defend against attacks from the local people. The ethnic inhabitants migrated from the north to the south to flee the wars, but had to face the hostile natives in the beginning (Figure 2), and so on.

![Figure 2: Different vernacular buildings.](image)

**1.2.2 Climatic zones and civil thermal infrastructure provision**

One of the most commonly cited classification systems, the Köppen-Geiger system, classifies the overall world climate types into Cold Climate, Temperate Climate, Hot-arid Climate and Warm-humid Climate (Lohmann et al., 1993, Kottek et al., 2006). However this is not specific enough for China. With a vast territory of 9,600,000 square km (excluding ocean area), the national Building Code (National Building Code) divides China into five climatic design zones (Figure 3). The current thermal design situation of each zone is as follows:

**Severely cold region:** Heating in winter is the key problem in this region. District heating is the main system in urban areas. Cooling by central air conditioning equipment is generally only provided in high-standard public facilities. Harbin is the typical representative city.
**Cold region:** Heating in winter is necessary and is generally provided by district heating systems in urban areas. Cooling by central air conditioning systems is provided in high-standard public facilities, while cooling by individual air conditioning units is becoming increasingly popular for apartments. Beijing is the typical representative city.

**Hot-summer/cold-winter region:** There are no district heating or cooling systems, even in urban areas. The absence of civil infrastructure has resulted in increasing popularity of air conditioning systems, both in public and residential buildings, as a result of increased personal income. Shanghai and Nanjing are the typical representative cities.

**Hot-summer/warm-winter region:** Air-conditioned cooling has grown sharply in this region. Heating is only provided in high-standard public facilities by air conditioning equipment. Guangzhou is the typical representative city.

**Temperate region:** The climate is temperate all through the year. Heating and cooling are only provided in high-standard buildings. Kunming is the typical representative city.

Another feature of China’s climate is that it is subject to strong monsoons on a national level, which makes southern China even hotter and more humid in summer and northern China even colder and drier in winter. Compared with other regions located at the same northerly latitude, it is 14-18°C colder in winter in north-east China, 10-14°C colder in the central and lower basin of Yellow River, 8-10°C colder on the south bank of Yangtze River, and 5°C colder in south-east coastal areas. Meanwhile, the average humidity is higher throughout the year in eastern China (Tu and Wang, 1996).

A specific case in the hot-summer/cold-winter zone was scrutinised to determine the current status and to identify potential improvements in how a residential area in this climatic zone could be sustainably constructed. With the economic growth, people in this climatic zone are demanding better indoor climate, which cannot be supplied by civil infrastructure, and thus energy issues concerning thermal comfort have become the central issue of sustainability, while other issues have been somewhat neglected.
2 Research Methodology

Since the purpose of this study was to identify pathways to sustainable urbanism in China, the main method used to carry out the research was case studies. Three Chinese cases, different in building type, scale, location, investment and objectives, and one Swedish case were selected to define basic ideas on sustainable building and development. A literature review was the main method used for the first case (Modern Vernacular Architecture), while site visits and interviews were carried out as complements for the other cases.

In the specific detailed integrated sustainability analysis of the Landsea Housing Project in Nanjing in the hot-summer/cold-winter region, a number of interviews were conducted with staff at the developer's offices. These were supplemented with field visits and discussions with residents in the area in order to verify the reliability of the data provided by the developer. The Landsea Housing Project was also compared with Hammarby Sjöstad, a Swedish residential project, from perspectives of environmental programme, stakeholder cooperation model, etc.

The study generally consisted of three consecutive academic stages: Firstly, the challenges of sustainable urbanism on a national scale were discussed, then efforts were devoted to the development of Green Building, which is regarded as the goal of sustainability in the building industry. Finally, the research focused on the Landsea Housing project, a specific green residential project, to document concrete practical experiences of how residential areas in China could be constructed in a more sustainable way.

Industrial Ecology is an innovative instrument used for research. As the backbone of Industrial Ecology, systems thinking was another important methodology embedded in the whole research process to perform the case study and analyse the data and results. Systems thinking is of help in identifying the strategy and mechanism embedded in the procedure. The residential project was analysed from the perspectives of technology, economics, environmental impact and social aspects.
3 Theoretical framework

The theoretical framework of this thesis consisted of three parts.

i) Industrial Ecology tools, such as Life Cycle Assessment, Material/Energy Flow Analysis, Integrated Sustainability Assessment, etc., were highly important in analysing the physical flows within certain system boundaries qualitatively and quantitatively, and also in identifying the roles of different participants during the residential process.

ii) The external conditions which affect the residential development were analysed. They included the current situation of the building industry, legislation and standardisation, indoor thermal comfort and demands related to economic growth.

iii) Case studies contributed the main body of the field research. The three Chinese cases and one Swedish case selected were used to define the basic ideas and to guide further sustainable development.

3.1 Industrial Ecology as an analytical method

Residential development is a complex process, involving multiple stakeholders such as government, developers, engineers, contractors, residents, etc., and also different physical flows such as water, solid waste, energy, foods, etc. The development also lasts a long time through phases including construction, operation and demolition. Nowadays decisions regarding residential development are becoming increasingly complicated because decision-makers have to take into account social, economic and of course environmental aspects. As regards the complexity, analytical decision-making methods provided by Industrial Ecology could help key decision-makers choose the most sustainable solutions.

3.1.1 Life Cycle Assessment and Life Cycle Costing

LCA is a tool applied for analysing the life cycle of a product or a service by evaluating its different flows (material and energy) and its environmental impacts throughout its lifespan. It is often described as ‘Cradle-to-grave’ which means analysis of the materials used in making a product or a service, from the extraction of materials and energy to the return of the materials to earth.

A Life Cycle Perspective helps to set up a systematic approach to analyse the whole life of an environmental issue, so that ‘out of sight, out of mind’ and ‘problem shifting’ can be prevented. It also helps to trace the environmental burdens to their origins. For example, some ‘hi-tech’ buildings use a lot of complicated and delicate equipment to reduce energy consumption and are declared to be energy-efficient buildings. However, if the energy and resources consumed by producing the equipment and maintaining it are taken into account using a life cycle perspective, these hi-tech buildings may turn out to be high energy-consuming products compared with the lower-tech options.

Life Cycle Costing (LCC) is a tool that looks at the entire life cycle of products, processes or activities and calculates the entire life cycle costs, which include all internal costs plus external costs incurred throughout the entire life cycle. The internal costs include conventional costs
and less tangible hidden, indirect company costs. External costs are those for which a company is not responsible at a specified time, in the sense that neither the marketplace nor regulations assign such costs to the company.

LCC aims at enabling investment options to be more effectively evaluated considering the impact of all costs, rather than only initial capital costs, assisting in the effective management of completed building a project, and facilitating choice between competing alternatives. LCC specifies the location and provides a comparative analysis of how much current practice costs now and will cost in the future, compared with what an alternative practice costs now and will cost in the future.

LCA is a comprehensively used quantitative method, but in this thesis it was used in a qualitative way to set up a Life Cycle Perspective to analyse different stages of the life cycle of Green Building. LCA was also combined with LCC to evaluate the two selected cases, the Eco-office of Shanghai Institute of Building Science and the Landsea Housing Project, from an economic perspective. This included e.g. the pay-back time of additional cost in the Eco-office and a comparison between operational cost and initial cost in the Landsea Housing Project.

3.1.2 Material/Energy Flow Analysis

The aim of Material/Energy Flow Analysis (M/EFA) is to specify and quantify the flows of materials/energy into, through and out of specified system boundaries. This system could be on national, regional, community, company or even household scale. Generally, material/energy flows in society are determined in a quantified manner. The entire circular flow of materials/energy is considered from the extraction of resources over the production and fabrication, use and recycling of the materials/energy to the point of final disposal. The capacity of the environment to absorb pollution and emissions is also taken into consideration. There are two main approaches of MFA: analysis of the flows of bulk materials; and analysis of flows of a single substance or a group of substances (SFA = Substance Flow Analysis).

When applying M/EFA, spatial boundary level is a key factor influencing the results. Different levels have different issues and measurements. In a residential development, the flows of materials and energy can be divided into four stages: external supply or local production, transportation, distribution, and consumption. Each stage has different possibilities to reduce

![Diagram of Material/Energy Flow Analysis](image-url)

*Figure 4: Conceptual model of M/EFA of a residential area.*
the environmental impact (Figure 4).

Thus, the goal concerning M/EFA of a residential area is that eco-cycles should be closed on a residential or city level if possible, e.g.:

1. Natural resource consumption should be minimised.
2. The overall consumption of energy should be reduced, and the use of exergy maximised.
3. Energy should only come from renewable sources and be based on local sources as much as possible.
4. Clean water consumption should be reduced.
5. Sewage should be utilised for energy recovery and its content of nutrients should be recycled to farmland.

3.2 External conditions analysis

3.2.1 Challenges of China’s urbanism

The past 30 years (1978-2008) have seen rapid, large-scale urbanisation in China, both as a force and as a result of fast economic growth, which has been accompanied by increasingly critical challenges along with a drastic physical and social transition. However, this development is far from sustainable and has caused a series of problems, which pose a challenge to continuing development. These challenges exist in nearly all aspects and can be summarised thus:

1. Large population and fast economic growth, which together have resulted in rapid, large-scale urbanisation.
2. Energy and resources scarcity, which is aggravated by the large population and low efficiency of utilisation and has led to energy/resources-intensive urbanisation.
3. Comprehensive and severe environmental degradation caused by uncontrolled urbanisation.
4. Imbalance of development between west and east, rich and poor, urban and rural, etc., which is exacerbating social inequity and generating severe conflicts between different social classes.
5. Tensions between the centralised political system and further development.

Specifically concerning the building industry, in 2006 China had a total building floor area of 40 billion m², and it is projected that an additional 28 billion m² floor area will be built before 2020 (Tu and Wang, 2004). However, 95% of the 40 billion m² in existing buildings and 80% of the 2 billion m² new buildings per year are energy-intensive (Tu and Wang, 2004). This is because of:

- Poor exterior wall insulation
- Poor windows: poor draught exclusion, low-quality glazing
- Improper design: not climate relevant, too reliant on ACMV
- Low-efficiency management.
As one of the consequences, the proportion of total energy consumption in China consumed by buildings rose from 10% in 1970s to 27.45% in 2001 (Centre of Energy Efficiency in Buildings, 2007). This is still rising rapidly due to the rapid urbanisation and improved interior comfort of new and retrofitted buildings, as well as the bad building quality.

3.2.2 Legislation and standardisation

Green Building is specifically defined according to the Chinese context as the creation of buildings that are ‘energy-efficient, land-efficient, water-efficient, and material-efficient’, emit ‘minimal pollution’ during their entire life cycle, and meet specifications on the indoor environment. One of the main objectives of Green Building is to save energy by as much as 50% compared with buildings constructed under the 1980s building code without any specific energy-efficiency adaptations (National Standard, 2005).

China, with the biggest population and nearly lowest resources per capita in the world, has established sustainability as its main development strategy and has introduced series of policies, specific design codes and laws since the early 1990s to promote the development of Green Building. These include:

- Thermal Design Code for Civil Building, GB 50176-93, 1993
- Energy Conservation Law, 1998
- Design Code for Heating Ventilation and Air Conditioning, GB 50019-2005
- Evaluation Standard for Green Building, GBT50378-2006, 2006
- Guidelines for Green Residential Area Construction, 2006
- Renewable Energy Law, 2006
- Energy saving Law, 2007
- ‘100 Demonstration Green Buildings’ programme, funded by Ministry of Construction, etc.

These policies and laws have greatly facilitated the development of Green Building (GB), and within them, the Design Code and Design Standard are the rigid legal bottom line that must be
met by all new and retrofitted buildings. The standards for ‘Green Building’ and ‘Green Residential Area Construction’ are an optimal selection. The bottom line mainly focuses on energy efficiency in the operational stage of an individual building through design and construction monitoring.

In contrast, the Guidelines for Green Residential Area Construction cover a comprehensive programme of a residential area’s life cycle. They include energy efficiency, renewable energy supply, water supply and recycling, waste treatment, land efficiency, indoor climate and health, maintenance, material recycling, and so on.

The GB Evaluation Standard for Green Building is a Chinese rating system for green practices. Combined with The Guidelines for Green Residential Area Construction, it responds to the specific Chinese context, for example land scarcity and water shortage, as well as relatively lower indoor thermal comfort, trying to promote Green Building through incentives and tax refunds from the government.

Figure 5 shows the current legislative framework for green residential building development in China. It is obvious that the bottom line only focuses on energy-efficiency and neglects the issues of energy supply, pollution and resources. The optimal standard has a broader perspective, but is still confined to the residential area level. A systematic approach that covers the whole built environment has yet to be established. There is still a long way to go for China to reach the goal of sustainable development.

### 3.2.3 Indoor thermal comfort and economic growth

There are two major standards to describe indoor environment: health/ill-being and comfort/discomfort (Assefa et al., 2007). Health/ill-being is the basic standard as buildings...
being a shelter from nature for humans, while comfort/discomfort places a higher demand on the indoor environment. As discussed by previous studies (e.g. Markus and Morris, 1980; Rosenlund, 2000; Yao et al., 2006), thermal comfort is associated with two primary categories of parameters:

Environmental: 1. Air temperature, 2. Air speed, 3. Relative humidity, 4. Radiant temperature; and Individual: 5. Metabolic, 6. Clothing. According to these factors, a comfort diagram can be drawn up as shown in Figure 6 (Rosenlund, 2002).

![Figure 6: Example of a comfort diagram for: DISC±0.5; 0.6-1.0 clo; 1met; v=0.1-0.5/s. After Markus and Morris (1980). Fifty-five combinations of parameters were found.](image)

Since comfort is a rather subjective experience, some other factors, which are briefly mentioned by researchers from developed countries, are especially important for people with relatively lower incomes living in developing countries. These factors include:

1. Expectations of comfort influenced by economic status and sensitivity to the costs of energy consumption.
2. Degree of tolerance to discomfort.
3. Personal behaviour regarding indoor clothing preferences, etc.

These factors are exemplified by the use of air conditioners during summer and winter. A survey on the use of air conditioners in a lower-middle level residential district (3000 households) in Shanghai (Zhong and Long, 2003), which has a similar climate to Nanjing, showed that 95.2% of households owned one or two air conditioning units, but 73% of these households would not turn on their air conditioners in summer until they felt ‘very hot’ at home, while 47.8% would not turn on their air conditioners (heating) in winter until they felt ‘very cold’ at home, with 37.3% never turning on air conditioners in winter. On the other hand, some households turned on their air conditioners once somebody was at home, with the proportion of this household type rising sharply as the economic situation improved.

The average standard of the indoor climate in Nanjing is just beyond the level of poor health,
and much lower than that of comfort, especially during extreme weather. However, with the increase in income, the demand for better thermal comfort is apparent. Due to the poor performance of air conditioners in winter and the lack of civil hot water supply, the domestic gas-fed boiler becomes necessary for upper middle-level households, combined with a floor-heating system to provide space heating in winter and hot water throughout the year. A survey within the present study on the amount of natural gas consumed for space heating in winter showed that 0.35-0.55 m³ gas/m².day was needed, with the amount varying depending on the temperature and running time set by residents, as well as boiler efficiency.

The climate in Nanjing is generally rather extreme. The city lies in the hot-summer/cold-winter zone of China, where the average temperature in January ranges from -0.4 to -5.9 °C and the average temperature in July rises to 25.9-31.4°C. The humidity is high all year around, 76% in January and 80% in July (China Meteorological Data Sharing Service System), making the feeling of coldness and heat much more severe in Nanjing. However, due to the low standard of national thermal design code, there is no infrastructure for district heating and cooling in the city or in rural areas.

Generally, heating and cooling is only provided during extreme weather periods at individual household level by various indoor methods, which vary greatly depending on the financial circumstances of different households. These methods include electric fans for cooling and domestic stoves for heating, or just natural ventilation for cooling and wearing more clothes indoors to keep warm. Since the early 1990s, individual air conditioning units have become increasingly popular in households in Nanjing due to the increasing family income accompanied by a higher demand for indoor comfort. This popularity has even resulted in the new design code for apartments, providing additional exterior air conditioning decks. Figure 7 shows the rapid growth in air conditioner ownership in Nanjing.

![Figure 7: Ownership of air conditioners per 100 households in Nanjing, China.](image)

Source: Statistical yearbook of Nanjing, 1997-2007

Some reasons for the popularity of air conditioners in Nanjing are:

1. Convenience of providing heating, cooling and dehumidification with the same equipment.
2. Relatively low initial costs.

3. Flexibility of utilisation in terms of control and maintenance depending on the specific conditions of different households, such as economic situation, personal desire for indoor comfort, etc.

4. Easy billing system by electricity consumption.

5. No other competitive alternatives with all functions of heating, cooling and dehumidification, etc.

However, some of the disadvantages of air-conditioners are:

1. Low performance in extremely cold periods and some types switch to electrical heating during extremely cold periods.

2. Air-flow disturbance and noise caused by convection, which is the main thermal distribution method.

3. Insufficient ventilation, which causes low indoor air quality.

4. Moisture condensation on interior surfaces during cooling in summer, which can be the cause of low indoor health.

5. From an urban perspective, mass utilisation of air conditioners in summer enhances the hot-island effect, which results in low efficiency on macro level.

To sum up, the indoor climate in houses in Nanjing is very poor during extreme periods, since cooling and heating systems are generally lacking. This undesirable situation is aggravated by the poor building envelope. Furthermore, those apartments equipped with air conditioners have to consume enormous amounts of electricity for the desired level of thermal comfort.

### 3.3 Case studies

#### 3.3.1 Green Building development in China

China, as a large developing country, generally has a wide variation in geographical types, climate patterns, vernacular buildings and different living styles. Green Building is essential for China’s sustainability strategy and it could have many typologies. Following the promotion of Green Building by the government, thousands of square metres of buildings classed as Green Building have been constructed and more are under construction since 2000. Generally, these Green Buildings can mainly be categorised into three types, Modern Vernacular Architecture, Eco-office, and Mass Housing Project.

*Modern Vernacular Architecture* tries to rethink traditional architecture and adapt the old housing ideals to the modern life, but without too much additional consumption of energy and resources. The old wisdom embedded in vernacular architecture shows the importance of adaptation to local climate and geographical conditions in order to produce a good built environment in an efficient way. This principle of adaptation has been largely forgotten by contemporary architects.
Eco-offices generally represent the official idea of Green Building, and function as demonstration projects. Most of the existing Eco-offices were funded by government rather than by commercial companies, which are market-orientated. The ‘green’ idea is somewhat regarded as technical equipment, which to some extent makes such offices not very cost-benefit effective and also difficult to generalise. However since 2005, there is a new requirement for Green Buildings by the Ministry of Construction that the additional cost should not exceed 20% of the reference building.

Following the rapid urbanisation in the past 20 years and also stimulated by government economic incentives, some real estate companies also have implemented the Green Building ideas in their Mass Housing development. These real estate projects have directly responded to China’s specific situation and are trying to use Green Building as a marketing strategy.

A typical example of a Mass Housing Project is the Landsea Housing Project in Nanjing. The development company has been so successful that it has expanded its business to nearly all the major cities in hot-summer/cold-winter areas. It has also received government awards for Green Building. For example, the Nanjing project was recognised as a demonstration project by the National Ministry of Construction in 2005 and the Landsea Housing project in Hangzhou won the prize for ‘Green Practice’ awarded by the Asian Habitat Society in 2007. The company’s Wuxi Project was named as ‘Key Project in the 11th 5-year plan’ by the National Ministry Housing and Construction (former Ministry of Construction) in 2009. The company itself also claims to be a ‘Leader in Green Residential Development’.

3.3.2 Modern Vernacular Architecture

Cave House is a typical housing typology in the upper and middle basin of Yellow River, where the Yellow Earth Plateau is located. The climate there is arid, hot in summer and cold in winter. The thick layer of yellow earth is dry and load-bearing, so it is easy to dig caves in the earth. Cave House has been a main rural residential type in this area for thousands of years and is still housing large numbers of rural inhabitants (Figure 8).

There are three types of Cave House depending on how the caves are created: cliff-side caves, sunken-yard caves, and independent caves. Cave House has both advantages and disadvantages.

Advantages:
- Low-price and easy construction
- Local materials and local farmers as builders
- Thick earth as a very good insulator, which makes the cave cool in summer, warm in winter
- Utilisation of steep slopes, which are not suitable for normal construction and farming.

Disadvantages:
- Poor natural lighting inside
- Poor ventilation
- No indoor sanitation facilities.

Based on the above analysis, a concept of New Cave House has been formed by some researchers and some New Cave Houses have been built, one of which is *Dongxin* Project.

![Old Cave House 1](image1) ![Old Cave House 2](image2)

**Figure 8: Old and New Cave House**

*Dongxin* Project is a large-scale cave housing project, with a site area of 28,000 m² and a total floor area of 31,500 m². The project was finished in 2004 and housed 322 households. It provides better infrastructure on neighbourhood level, such as roads and sewerage system, and modern facilities inside the cave, such as electricity, heating, gas, water and indoor toilets. Some design innovations also help to improve the indoor climate greatly, for example a small back sunken yard for ventilation and natural lighting, solar heater providing hot water, and natural cooling through underground air ducts. The cave structure is designed and built in a modern engineering way to meet the requirement for durability (Duan and Li, 2004).

**Discussion**

In general, the *Dongxin* Project is a good example of rethinking traditional architecture and it attempts to adapt the old housing idea to the modern life, but without too much additional energy and resources consumption. The project shows the capability of vernacular buildings for survival in the modern and westernised era. Furthermore, affordable technology, indigenous technique and native Chinese wisdom are revealed in the project. The architect's efforts and respect for the traditional culture could be generalised to other projects.
However, the project is rather geographically specific and is not responsive to the main challenges of rapid, large-scale urbanisation in China. To some extent, the project is not efficient in land use, since all the houses are one-storey due to the nature of the ‘cave’.

To sum up, the Dongxin Project could be regarded as ‘green’ not only in environmental protection but also in cultural conservation, although it does not provide answers for the critical challenges in cities.

3.3.3 Eco-office: Office of Shanghai Institute of Building Science (SIBS)

SIBS Eco-office is a demonstration project funded by the Shanghai Government. It won first prize in the ‘Green Building Innovation Competition, 2005’, which was organised by the Ministry of Construction. The project, located in a suburban of Shanghai, has a floor area of 2000 m² and functions as a branch office for Shanghai Institute of Building Science. It was built in 2004 (Figure 9).

The Eco-office implemented a number of technical equipments and methods to build a green building, such as:

- Good insulation & windows: Exterior wall, $K=0.27-0.33 \text{W/(m}^2\text{K)}$, Windows, $K=1.65-1.83 \text{W/m}^2\text{K}$
- Mechanically adjusted exterior shading
- Enhanced natural ventilation by solar heater during temperate seasons
- Renewable energy: solar heater and solar cell
- High-efficiency air-conditioning equipment
- Water recycling and local micro grey water treatment
- Roof garden & interior planting.

According to the SIBS report (Shanghai Institute of Building Science, 2005), the building’s annual energy for heating and cooling is 30 kwh/m².year (reference building: 100 kwh/m².year), and the local grey water plant generates 20 tons of treated water per day from recycled domestic wastewater and storm water. Eco-Office construction cost RMB 4600 yuan/m² (reference building: 3100 yuan/m²). The cost has increased by 48% and the pay-back time is about 22.3 years. The high cost is partly because of the small scale of the building as a
demonstration project.

**Discussion**

The SIBS Office is a government-funded project. Its initial idea was to demonstrate the green technology, and thus the design idea is rather technology-dependence. Since it was not funded by market-orientated sources it is not very cost-effective, so it is difficult to generalise. Since 2005, there is a new requirement for Green Building by the Ministry of Construction that the additional cost should not exceed 20% of the reference building.

The project is located in a suburban town, but the SIBS headquarters are located in the city centre. Most of the staff working in the Eco-office live in city and have to commute to the Eco-office every day. From this point of view, the building is not ecological on an urban level.

To sum up, the SIBS Eco-Office represents the official idea of Green Building and functions as a demonstration project. It has done a good job in terms of demonstrating, although the ‘green’ idea is somewhat regarded as technical equipment and, since it was funded by government, the cost was not very sensitive to market forces. The Eco-Office shows the initial stage of the green idea and mainly focuses on the level of individual building, other than city level, so that the greenness is limited to a certain extent. Systems thinking on the Green idea should integrate different levels of built environment to have a synergistic effect.

**3.3.4 The Landsea Housing Project in Nanjing**

**General description**

With the boom in real estate in China, the idea of Green Building has inevitably been commercialised and introduced in mass housing projects, including the Landsea Project in Nanjing.

![Figure 10: Site plan of the Landsea Housing Project.](image)

‘Landsea’ is the developer’s English transliteration of its Chinese name. The housing project is located in the new district of Nanjing, West Riverbank New Town, which lies to the south-west of the old town. A metro line launched in 2005 connects this new district with the main city and one of the stations is about 500 m from the Landsea Housing site. The developer obtained a 70-year lease on the land from the local government, with some restrictions on maximum total floor area, set-backs along roads, maximum building height, building footprint
The Landsea Project is a typical gated residential project in China. To achieve high land efficiency, namely in terms of FAR, the project consists of 11 eighteen-storey high-rise apartment buildings and about 20 six-storey medium-rise apartment buildings (Figure 11). The Landsea Project is a typical provider paradigm (Gu, 2007) for mass housing development, and residents have little influence on the final product, namely apartments. The developer constructs the apartments according to mass production principles – centralised, standardised and industrialised – and then sells them to residents at the market price.

**Technical analysis**

The developer entitled the project ‘scientific housing’ because the technical system in the buildings is rather new and ‘high-tech’ for Nanjing. It comprises a low-exergy system, which is a combination of surface geothermal heat-pump, ceiling heating and cooling, independent
mechanical ventilation and good building envelope.

The primary energy for heating and cooling is produced by the heat pump from surface earth, while heating and cooling are provided by the water running in tubes embedded in the concrete ceiling slab. Technically, heat pump technology is especially suitable for the hot-summer/cold-winter climate, because the system not only gets heat from the earth in winter but also returns heat to the earth in summer, so that the thermal balance of surface earth is easier to acquire. The main thermal transfer mechanism in buildings is thermal radiation, which is more effective than convection and conductivity, and thus the water inside the tube can be low-temperature for heating and high-temperature for cooling, i.e. more energy-efficient. Independent mechanical fresh air ventilation is also part of the system.

The building envelope has been improved greatly compared with normal buildings. The exterior wall and windows have a lower thermal transfer coefficient and the adjustable exterior sun screens also greatly help reduce excess solar heat gains in summer.

The objective of indoor climate control is to keep the temperature no higher than 26°C in summer and no lower than 20°C in winter with sufficient fresh-air ventilation. Compared with the normal apartments in Nanjing, the indoor thermal comfort in Landsea apartments is excellent, particularly in winter.

Table 1: Comparison of K values, the data on developed countries reflect the situation in the mid-1990s.

Sources:
X: Rosenlund et al., 2005: p.16.
Y: Yao et al., 2006: p.60

<table>
<thead>
<tr>
<th></th>
<th>Exterior wall (W/m²K)</th>
<th>Window(W/m²K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsea Project</td>
<td>0.3</td>
<td>2.0</td>
</tr>
<tr>
<td>China New Building code (JCJ134-2001)</td>
<td>&lt;1.5</td>
<td>2.5-4.7</td>
</tr>
<tr>
<td>Apartments in Nanjing before 2000</td>
<td>&gt;2.0</td>
<td>6.0-6.5</td>
</tr>
<tr>
<td></td>
<td>(plastered 24 cm bricks, without extra insulation)</td>
<td>(single glazing with metal frame)</td>
</tr>
<tr>
<td>Beijing Code 1986</td>
<td>1.28</td>
<td>6.40</td>
</tr>
<tr>
<td>Code 1995</td>
<td>0.82-1.16</td>
<td>4.00</td>
</tr>
<tr>
<td>Southern Sweden, old code</td>
<td>0.30</td>
<td>2.00</td>
</tr>
</tbody>
</table>
The running fee charged to residents is 21 yuan/m².year. The building cost of apartments has risen by 400 yuan RMB/m², but the apartment selling price has increased by 3000-4000 yuan RMB/m². The project's pivotal marketing strategy was actually the indoor thermal comfort and the promotion of a high standard of living. It represented a high social class product by the high indoor comfort compared with normal residential buildings.

Water recycling was implemented in phase 1 to recycle wastewater from kitchens and showers to water vegetation and wash shared outdoor areas. Actually this system was so effective that it produced more recycled greywater than needed. However the water recycling system was cancelled in phase 2 and 3 because of the cheap price of fresh water and insufficient demand for treated greywater in the Landsea project itself.

Assessment of the Landsea Housing Project

As a real estate project, Landsea Housing directly responds to China’s specific conditions, such as high density, improving standard of living, local climate, etc. The interior thermal comfort has been improved greatly compared with other normal apartments in Nanjing, though it is merely the same or even lower than that in developed countries. However, when the indoor comfort is being discussed in a developing country, the standard of living is considerably different and this must be taken into account.

Good building envelope is the key factor in energy-efficiency. In hot-summer/cold-winter regions, it consists of good wall insulation, good windows, and exterior sun shading. From a Life Cycle Perspective, the additional investment on envelope could be paid back within a reasonable time. In the specific case of the Landsea Project, the residents get a high level of thermal comfort at a low additional cost. However, enormous energy is needed for buildings with a bad envelope if high indoor thermal comfort is to be achieved.

Since the Landsea Housing Project is a market-orientated project, measurable indicators and performance-based evaluation are essential to marketing success, as has been shown by its good sales. The technology implemented in the project is normal technology rather than fascinating high-tech equipment, which is sometimes very deceptive.
Generally, *Landsea* Housing is a commercial project and it is also market-orientated. In terms of Cost-Benefit Analysis of the building cost itself, *Landsea* is an affordable practice, improving thermal comfort greatly with a limited cost and it could be recognised as Green Building practice in this regard. However, the project has been over-exploited by developer, since although the additional building cost, compared with other normal apartments, is only 400 yuan RMB/m², the actual additional price charged for apartments is ten times this amount, so the apartments can only be afforded by high-level consumers. The idea of Green Building was used as a market strategy and profit lever in the *Landsea* Project. Due to its marketing campaign, the project has thus delivered to the public the image of Green Buildings being very expensive buildings. This misconception has had a bad influence on the acceptance of Green Practice in the longer term.

### 3.3.5 *Hammarby Sjöstad* in Sweden as a reference

*Hammarby Sjöstad* in Stockholm is one of the biggest residential developments in Europe. It is a typical urban project, located in the south-east of Stockholm city. The project covers 145 ha, including a lake. Most buildings in the project have been completed (Figure 12). The general vision of *Hammarby Sjöstad* is 'twice as good', which means that the environmental load from *Hammarby Sjöstad* is meant to be 50% lower than the corresponding level for housing areas from the early 1990s. This goal was developed into series of sub-goals covering energy, transport, water, building materials, etc.

![Figure 12: Site plan of *Hammarby Sjöstad*.](image)

*Source: Brochure from Environmental Centre at Hammarby Sjöstad*

Like the *Landsea* Project, the local government owned the land and leased it to several developers. The City of Stockholm developed Design Guidelines and an Environmental Program, and these were guiding documents for all stakeholders working in the project. The Environmental Program for *Hammarby Sjöstad* focused on environmental issues in both its
planning and implementation stages. The programme is intended to function as a planning tool and provide guidelines for the development of the area, while contributing towards a collective vision of vital objectives within the environmental sector to be shared by the City, the developers, and the construction companies. For the environmental aspects the environmental programme (EP) can function as a planning tool and provide guidelines for the development of the area. The EP can also support the development of a collective vision of vital objectives to be shared by all stakeholders taking part in the development process.

In the case of Hammarby Sjöstad, the vision was gradually developed in a participatory process among the stakeholder groups. The vision of sustainability was expanded both on spatial and temporal scale. To facilitate these discussions, common goals were developed concerning the operational objectives for the area. Examples of these goals could be:

1. Eco-cycles should be closed on a residential or city level if possible.
2. Natural resource consumption should be minimised.
3. Overall consumption of energy should be reduced, and the use of exergy maximised.
4. Energy should only come from renewable sources and be based on local sources as far as possible.
5. Clean water consumption should be reduced.
6. Sewage should be utilised for energy recovery and its content of nutrients should be recycled to farmland.

Figure 13: Industrial Ecology model of Hammarby Sjöstad. Source: Brochure from Environmental Centre at Hammarby Sjöstad
7. Building materials should be renewable or recyclable. The materials should be friendly for environment and health.

8. The local biodiversity should be strengthened through the establishment e.g. of green areas and wetlands. These areas should be continuous in pattern.

9. The need for private transport should be reduced to a minimum.

In order to visualise these operational goals and to discuss the system boundaries for an eco-cycle model, an Industrial Ecology model can be used for the area. An example of such a model is given in Figure 13, which shows how the energy and material flows are closed on local level.
4 Proposals

4.1 Broader picture of Green Residential Building Development

Compared with Hammarby Sjöstad, energy efficiency is obviously the main issue in the Landsea Housing Project and other environmental issues such as pollution, waste, renewable resources, bio-diversity, etc, are not considered. Furthermore, the integration of residential building into the city has yet to be understood and emphasised. To some extent, this reflects the current situation in Green Residential Development in China, as discussed earlier in this thesis. The next step is to move forward from energy efficiency to integrated Green Residential Development.

A broader picture of Green Residential Building covering three aspects as discussed above (social, economic and environmental) will be of help to development. The environmental goals should be set not only on energy efficiency, but also on more comprehensive issues within wider spatial boundaries and a longer time span, including energy, water, land use, waste, building materials, etc. concerning stages of construction, operation and dismantling.

4.2 Cooperation models

The building industry is a multiple stakeholder industry, involving government, developers, engineers, contractors, residents and so on. Different participants play different roles in sustainable development in terms of motivation and approach.

Government, as the body responsible for stewardship of sustainability on a macro level and in a long-term perspective, should enforce sustainability to society through legislation and act as an organiser. In both the Hammarby Sjöstad and Landsea Projects, local government owned the land and leased it to the developers, but these local governments acted differently in the two cases.

In the case of Hammarby Sjöstad, the municipality of Stockholm developed Design Guidelines and an Environmental Program, and these were guiding documents for all stakeholders working in the project. In the case of Landsea, when the land was leased to the developer, the local government only controlled the FAR of the land, set-backs along streets and some other economic factors. After the land had been handed over to the developer, the government had little control and made little contribution to the project on environmental issues except in terms of building codes and standards. To have a better influence, the local government should get involved more actively and propose a high-level and detailed sustainability strategy for the whole city and extend it to all developers. With its more centralised form of government than its counterparts in Europe, China could, and should, work more effectively.

A developer's main concern is profits and so it is reasonable for the Landsea Project to use Green Building as a marketing lever on company level. If a developer would like to adopt sustainable development, in this case energy-efficient building, as its main strategy, the profits could be ensured via two methods: reduced costs via energy-efficient technology, or strengthened marketing advantages resulting from stricter legislation and cost-benefit effective products. In the case of Hammarby Sjöstad, the Environmental Program acted as the stricter
legislation and became a prerequisite for all developers involved in the project. However in the Landsea Project, as a mono-developer project, there was no such common programme except the developer’s own concern about energy-efficiency from the marketing perspective.

Residents pay more attention to the quality of products and their price, and their awareness of sustainability could be fostered by education. The factors determining the residents’ choice to buy or not buy energy-efficient housings are mainly their own personal requirements and concerns about prices, with their awareness of sustainability being a secondary issue. Resident participation is also a highly essential element during the operation stage to achieve the goals. In Hammarby Sjöstad, there is an environmental information centre for the education of residents that also acts as an exhibition centre caring for visitors from all over the world. Via the information centre, residents are involved in the process and also encouraged to contribute to the sustainability goals.

The Landsea Project, initiated by a single developer with a single vision of marketing profits, is very exclusive, and due to its over-exploitation, has even created misconceptions on Green Building. The Landsea Project took Green Building as a marketing lever, while the residents in the Landsea Project were very passive and did not participate in the development process, but paid much more for the comfort they could get from Landsea because of the developer's marketing advantages. Thus, the Landsea Project has ultimately had controversial effects on the development of Green Building in China. However, the misconceptions about Green Buildings could be rectified if more developers followed the practice and the public acquired more knowledge of Green Building.

If an interaction model for the government, company and residents could be set up, the synergistic effect could function as a catalyst for Green Residential Building development. The two different models shown in Figure 14 and Figure 15 depict the potential relationships between local government, developers, residents and other service providers. In the Linear Model (Figure 14), the government is rather weak in promoting Green Residential Development and the linear process reduces the synergistic effect, even if any participant has interests. By contrast, the second model is more inclusive and relationships among different participants are much more interactive (Figure 15). The government can handle the building process more actively and effectively, and residents can also influence both the government
and developers. Service providers, such as architects, engineers, etc., only work for developers in the Linear Model, but they can also work for the government and residents besides the developer, thus acting both as knowledge-deliverers and capacity-builders among different participants, in the Interactive Model. By this, their jobs could be more meaningful and valuable for Green Residential Development.

4.3 From energy efficiency to Integrated Sustainability

Sustainability assessment of a residential area, which is a complicated built unit, should include economic, social and environmental aspects. Economic aspects are the cost of building the area, as well as those of long-term operation of the area. Social aspects include costs for the people living in the area, as well as accessibility by public transport, shopping areas, schools and kindergartens, indoor climate, etc. Resident participation in daily life in the maintenance of apartments is also very important in achieving sustainability in the project. Environmental aspects are energy, water, waste, etc., as discussed above.

It is obvious that all these aspects are related and thus the assessment must be integrated. Only by taking care of all aspects already in the planning phase will the longer-term sustainability of the area be assured. Different stakeholders will emphasise different aspects when planning the area and thus it is important to have sufficient time in the early planning process when the goals can be formulated and evaluated.

The overall sustainability aspects for the development should include:

1. Flexibility in the development process to change operating goals due to experiences and the assurance of new technology and knowledge.
2. The solutions must be tailored to the needs of residents and promote social inclusion and environmental responsibility.
3. Resident commitment and needs should be taken into account in order to influence the neighbourhood design.

4. The implementation should be used as leverage to develop new sustainable solutions for e.g. use of energy, natural resources, closing the loops for nutrients, reuse/recycling of waste and minimisation of private transport needs.

5. The solutions and measures used should not give increased costs that prevent the spread of experiences.

6. The experience, know-how and technology generated in the development process should be disseminated in order to contribute to sustainable development elsewhere.

These operational objectives should be formulated in harmony with other national and local objectives. It is important to realise that there are no absolute goals for sustainability but specific goals have to be formulated on the local level, taking national and global restrictions into account. After the general operational objectives have been developed in a cooperative manner, the specific goals for different sectors, e.g. energy, transport, waste, water and drainage, building materials, land use, etc., should be developed.

Compared with the Landsea Project, Hammarby Sjöstad, organised in an ‘Interactive model’, presented a clear example of how integrated sustainability can be obtained in a complex real life situation. Although China and Sweden are at different historical stages of development in terms of economy, political structure, democracy process, etc., experiences obtained from Hammarby Sjöstad can act as a reference for development in China. For example, both governments have control of the land, but the local authorities in Stockholm worked much more actively on environmental issues, while the authorities in Nanjing only imposed economic regulations on the land. This was caused by lack of awareness, less local know-how and also the fast development speed demanded by the market. Being more centralised, the Chinese government could learn much from its Swedish counterpart regarding coordinating and monitoring.
5 Summary of appended papers

Papers I-III describe the sequences of studies performed on sustainable urbanism in residential development in the course of this thesis work. In addition, the author has been involved in research on urban planning and design at the School of Architecture, Southeast University, China.

5.1 Paper I


The purpose of Paper I was to identify the main problems concerning long-term sustainable urbanism in China and compare the current conditions with those principles suggested by Kenworth for developing countries. Paper I summarised the main challenges as being:

1. Large population and fast economic growth, giving rise to rapid, large-scale urbanisation.
2. Energy and resources scarcity owing to the large population and low use efficiency, giving energy/resources-intensive urbanisation.
3. Comprehensive and severe environmental degradation caused by uncontrolled urbanisation.
4. Imbalanced development between geographical areas, income groups, social classes, etc., generating social inequity and severe conflicts between social classes.
5. Tensions between central government and developers.

These challenges formed the basis for further studies in Papers II and III.

5.2 Paper II


The main objective of Paper II was to investigate the current development of Green Building, which is regarded as the goal of sustainability in the building industry. The green buildings studied were categorised as: Modern Vernacular Architecture, Eco-offices, and Mass Housing Projects. Three cases, different in building types, scale, locations, investments and objectives, were analysed from social, economic and technical perspectives in Paper II in order to obtain a general image of how sustainable buildings are developed in China.

Three cases are: Modern vernacular architecture – Dongxin New Cave Housing Project, Eco-office – Office of Shanghai Institute of Building Science (SIBS), Shanghai, and Mass housing project – the Landsea Housing Project, Nanjing.

Paper II showed that China, a large developing country, has great variation in geographical types, climate patterns, vernacular buildings and different living styles. Green Building is essential for China’s sustainability strategy and it could take many different paths. An adaptive
and holistic approach should be found for the development of Green Building in China.

5.3 Paper III

Paper III involved a deep and detailed case study on the third case in Paper II, the Landsea Housing project in a hot-summer/cold-winter zone in Nanjing, and discussed how to develop more comprehensive frameworks, from energy efficiency to integrated sustainability, for residential areas in China. Hammarby Sjöstad, a cutting edge project in Stockholm, was also discussed as a reference area from which experiences could be drawn for China.

Obviously, energy efficiency is the central issue in the Landsea Housing Project and other environmental issues such as pollution, waste, renewable resources, bio-diversity, etc. are not considered. Furthermore, the integration of residential building into the city has yet to be understood and emphasised. This is partly because of the legislation structure and the narrow understanding of Green Building. For further development, the environmental goals should be set not only on energy efficiency, but also on more comprehensive issues on a wider spatial and temporal scale, including energy, water, land use, waste, building materials, etc. concerning stages of construction, operation and dismantling.

Paper III suggested that a broader picture of Green Residential Building covering three aspects, social, economic and environmental, would be helpful in development and an interactive cooperation model between different stake-holders should be set up to facilitate the fulfilment of the long-term sustainability goals.

5.4 Paper IV

The main objective of Paper IV is to implement Industrial ecology methods, such as LCA, MFA, in urban design process to obtain a systematic understanding of energy and material flows in urban area, thus optimize relevant ecological design methods.

The paper attempts to study the process of ecological urban design through the perspective of Material/Energy Flow Analysis from an architect’s view. The study includes how to control and adjust the production, transportation, distribution, and consumption of material and energy flows in built environment system, and how to analyze the relevant ecological design methods. The paper implements two environmental methods, Material/Energy Flow Analysis, the main one, and Life Cycle Assessment, as a paralleling one, to analyze the “integrated efficiency” of material and energy utilization in built environment and its meaning to sustainable design. Finally, the topic is exemplified by two cases, “Material Flow Analysis of household waste water Treatment” and “Energy Flow Analysis of energy for heating and cooling in buildings”.

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6 Discussion

6.1 Physical boundary and environmental issues

Environmental issues have different physical boundaries. Table 2 shows interlinks between different levels of physical boundary and related environmental issues. When applying Industrial Ecology, spatial scale is a key element.

Table 2: Physical boundary and environmental issues.

<table>
<thead>
<tr>
<th>Level</th>
<th>Environmental issues</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global</td>
<td>Climate change, CO₂ emission reduction</td>
</tr>
<tr>
<td>Sub-continental</td>
<td>Smart and adaptive production and utilisation of energy and resources, environmental protection, bio-diversity conservation.</td>
</tr>
<tr>
<td>Regional</td>
<td></td>
</tr>
<tr>
<td>City &amp; Urban District</td>
<td>Local climatic features: bio-climatic planning, annual frequent winds</td>
</tr>
<tr>
<td></td>
<td>District circulation, connection between land use and urban transportation, transit-orientated development</td>
</tr>
<tr>
<td></td>
<td>External energy acquisition: Energy flow analysis</td>
</tr>
<tr>
<td></td>
<td>External resources acquisition: Material flow analysis</td>
</tr>
<tr>
<td>Urban Neighbourhood</td>
<td>Local climate optimisation, bio-climatic planning and design - landscape ecology</td>
</tr>
<tr>
<td></td>
<td>Assessment of local natural resources: Water, fauna and flora, bio-diversity – analysis of natural filtration, rain harvesting, flood control</td>
</tr>
<tr>
<td></td>
<td>Density: Sub-division of land, FAR analysis, effective and densified land use, mixed land use</td>
</tr>
<tr>
<td></td>
<td>Circulation: High effective and low energy-consumed</td>
</tr>
<tr>
<td></td>
<td>External circulation: Articulation with urban network</td>
</tr>
<tr>
<td></td>
<td>Internal Circulation: Vehicular Movement, Bicycle, Pedestrian</td>
</tr>
<tr>
<td></td>
<td>Local energy production and use: Solar Energy, Wind, Geo-Energy</td>
</tr>
<tr>
<td></td>
<td>Public horizontal circulation: People, Material</td>
</tr>
</tbody>
</table>
### Industrial waste: Circular industry, pollution control and reuse

- Daily waste: Organic, non-organic
- Human defecation: Bio-mass, bio-fermentation
- Local agricultural development and greenland planning – productive landscape

### Building Cluster & Single Building

- Waste treatment: classification, recycling, reuse
- Industrial waste: Circular industry, pollution control and reuse
- High comfort, low energy, low emission, reuse
- Architectural design: Site, effective space, volume
- Exterior envelope
- Interior environment
- Recycling and less utilisation
- Equipment
- Smart and automatic control

**Figure 16:** Conceptual model of built environment in a Life Cycle Perspective

The spatial levels of the physical boundaries in the built environment can be integrated with its temporary life cycle to establish a holistic conceptual model to facilitate environmental issues (Figure 16).
6.2 General Assessment of Green Building development in China

The proportion of energy consumption by the building sector in China is relatively low compared with that in developed countries, and the energy consumption per capita is much lower. This is partly because of low indoor thermal quality. However, it is obvious that with economic growth, Chinese households can afford more energy consumption to obtain more indoor thermal comfort.

Renovation of traditional buildings could not only improve inhabitants’ living conditions at a low cost, but also promote the historical culture and native wisdom, which is of great importance for developing countries. The old wisdom embedded in vernacular architecture shows the importance of adaptation to local climate and geographical conditions to acquire a good built environment efficiently. For example, the rivers in water-towns are used for transportation and as a cooling source in summer, while the heavy earth in cave houses acts as a good insulator. What is needed now is to determine how the old wisdom could be implemented into the more compact urban situation in order to respond to the specific challenges resulting from the huge scale urbanisation in China.

Both Eco-office and Landsea Housing Project are located in urban contexts, but they were initiated by different objectives. Government funding and subsidies are very important at the initial development stage of Green Building, but this could result in cost-benefit effects being ignored in green practices.

Landsea Housing Project responded to the practical situation from the beginning, taking green practice as a marketing lever, which ultimately had controversial effects on the development of Green Building. Furthermore, the inhabitants in the Landsea Project are very passive and are not participating in the process at all. If a platform for interaction between government, company and inhabitants could be set up, the synergistic effects could function as a catalyst for Green Building development.

To sum up, China, a huge developing country, has great variations in geographical types, climate patterns, vernacular buildings and living styles. Green Building is essential for China’s sustainability strategy and it could have many faces. An adaptive and holistic approach should be found for the development of Green Building in China.

6.3 Uniqueness of Nanjing, China

A fast rate of construction is needed to meet the social and market demand in China. Common problems in buildings are low thermal quality, high energy, and short life-span resulting from low quality and low initial investment. Thus Green Building is essential for China’s sustainability strategy in a long-term perspective and it could take many forms. An adaptive and holistic approach should be found for the development of Green Building in China.

Most current research about green buildings is based on conditions in the developed world, so the experience and knowledge obtained from developed countries must be adapted to the specific context in developing countries. Nanjing has a typical hot-summer/cold-winter climate with high humidity, which is not common in developed countries. The economic growth in
Nanjing is fast, and this is leading to a growing demand for interior thermal comfort. Obtaining a better standard of living with low energy increase is a key issue for sustainability in developing countries, especially for China with its huge population.

The Landsea Housing is located in an urban context, and responded to the practical situation from the outset. Its technical system has improved indoor climate greatly at a relatively low cost. When comparing energy consumption, different life styles must be taken into account, especially for a fast growing developing economy where standard of living is improving rapidly. Moreover, the main marketing point of the Landsea Housing is its highly improved indoor comfort which is very appealing, especially in the challenging climate of Nanjing.

The proportion of energy consumption by the building sector in China, as well as total energy consumption, is relatively low compared with that in developed countries, and the energy consumption per capita is even lower. This is partly because of low indoor thermal quality. However, comparing buildings located in a similar climate with similar indoor thermal quality, the energy per square metre for heating in Chinese buildings is generally three times that in their European counterparts because of bad building envelope, unsuitable designs and inefficient management (Rosenlund et al., 2005). Obviously, China cannot afford this huge energy waste if it wants to promote higher indoor thermal quality on a national level. Fortunately, the government and society are already aware of this and are trying hard to alter the direction of building developments as one component of the whole sustainable development programme.

With the economic growth, it is becoming more common for Chinese households to be able to afford more energy consumption in order to obtain higher indoor thermal comfort. However, the idea of thermal comfort is rather different from that in the developed countries, especially for those moving from a very low standard of indoor climate. It is not necessary to have the indoor thermal standard of developed countries in order to satisfy Chinese households. The parameters of the indoor climate could be adapted to the Chinese reality to save domestic energy consumption. For example, the recommended indoor temperature could be 2-4°C lower in winter and 2-4°C higher in summer compared with that in developed countries. In the case of the Landsea Project, the indoor temperature is set to 20°C in winter to 26°C in summer. These simple methods could save considerable energy without compromising the thermal comfort demanded by Chinese households.

To measure building energy consumption, indoor thermal comfort must be taken into account. Many buildings in Nanjing consume very little energy but have poor indoor comfort, which is the common situation in developing countries. These buildings cannot be classified as energy-efficient buildings, because when the energy they consume is compared against the comfort provided, the cost-benefit efficiency is rather low.

### 6.4 Economic growth, energy consumption and potential of China

To address the relationship between energy consumption and comfort, four scenarios are generally compared (Figure 16): High-energy/low-comfort (S1); Low-energy/low-comfort (S2); High-energy/high-comfort (S3); Low-energy/high-comfort (S4).
At present, most of the buildings in Nanjing are at the situation of S2, and some buildings are moving towards S3, which was also the situation of buildings in developed countries before the Energy Crisis. Even some buildings with a bad envelope are just struggling at S1, whereas S4 (Low energy/high comfort) is the objective of energy-efficient building. For the case of Nanjing, there could be an S5 option: very Low-Energy/moderate comfort.

Nearly all developed countries have experienced a high-energy/high-comfort period in building energy consumption (Figure 17). However since the Energy Crisis, they are moving to more energy-efficient buildings and have made great achievements. For fast-growing developing countries, the potential exists to avoid the high-energy period and get to the scenario of Low-energy/high-comfort (S4) or very Low-Energy/moderate comfort (S5) directly.

This energy scenario (S5) can also be extended to other environmental issues such as resources,
pollution, greenhouse gas emissions, etc. These issues can in total be expressed as scenario 6 (Low environmental load/moderate comfort). This could be an advantage for developing countries and could also be a benefit for the whole world.

### 6.5 Systems thinking

The building industry is an important component in achieving environmental sustainability because it consumes more than one-third of the total energy consumption and it has high potential to decrease environmental impact. However, due to the involvement of a large number of stakeholders and participants, technical innovation in this area is slow. The building industry is a complicated system with all those factors interacting with each other, which increases the complexity and uncertainty. Housing development is influenced by social, economic, environmental and cultural factors. It represents an interplay between municipality, developer, contractor, architect, engineer and inhabitant, etc. To achieve the objectives of energy-efficient building, systems thinking can help to identify the role of different actors and to better understand the relationship between these.

### 6.6 Further studies

This thesis presents a preliminary study of how residential development in China could be more sustainable in the long term. However, there are many more issues to be explored and discussed.

First of all, when discussing the Landsea Housing project, one feature was not mentioned. This project was a gated residential project and all three phases were gated blocks. This phenomenon of gated residential projects has prevailed in China since the 1990s, and has resulted in social segregation to some extents. If this became a common model of residential development in China, not only for high social level, but also for all other social levels, could it be called segregation? What is its social influence on the goal of sustainability? Another point is the size of the gated blocks. The average urban block in China is much bigger than that in European cities and has caused a lot of transportation problems. Is there an optimal size of gated blocks in this regard? Further studies should analyse the origin, formation, evolution, influence and potentials of the gated super-residential blocks in China.

Secondly, IE methods could perhaps be used to work more actively for environmental designers, for example architects and urban designers. Studies are needed on how IE methods, such as LCA, MFA and CBA, could be used by architects and urban designers, considering their less engineering background. As shown in this thesis, Industrial Ecology has been an innovative tool in the research of the integrated sustainability. Further studies should explore the great potential of IE applications in a qualitative way for environmental and energy design.
7 Conclusions

The building industry is an important component in achieving environmental sustainability because it contributes more than one-third of total energy consumption and it has great potential to decrease environmental impact. However due to the involvement of many stakeholders and participants compared with other industries, technical innovation in this area is rather slow. The building industry is a complex system with many factors interacting with each other, which increases the complexity and uncertainty. To achieve the objectives of Green Residential Development, systems thinking can help to identify the role of different actors and to better understand the relationship between them.

China has great variation in terms of geography, climate, vernacular building and lifestyle. Green Building is essential for China’s sustainability strategy and it should have its own character based on the uniqueness of the country. The current legislative framework for green residential building development in China mainly focuses on energy-efficiency and neglects the issues of energy supply, pollution and resources. China is thus still on a lower level of Green Building development where the understanding of the concept is very limited and needs to be expanded in the physical and temporal domain.

Technically, the Landsea Project achieved a high level of energy-efficiency, but neglected other environmental issues. However, the Landsea Project used Green Building as a market lever, and focused on energy-efficiency to meet the market demand for high thermal comfort and to maximise profits. This ultimately hampered Green Residential Development. Furthermore, the distinct roles of different stakeholders were not clear and no platform for collaboration was built. In contrast, Hammarby Sjöstad was initiated by the local government and its Environmental Program, covering comprehensive issues, acted as a common ground for all stakeholders. An Interactive Model greatly facilitated Green Residential Development in Hammarby Sjöstad.

These two cases illustrate different levels of Green Residential Development. A more developed strategy in China requires systems thinking like that in Hammarby Sjöstad, so experiences gained in Hammarby Sjöstad could hopefully be transferred and translated into the Chinese context. As a developing country, China also has potential to avoid the mistakes made by developed countries, but this potential relies on an adaptive and holistic approach and on establishment of a general sustainability framework for Green Residential Development in China.
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